FINITE ELEMENT SIMULATION OF DRIVE SHAFT IN TRUCK/SUV FRONTAL CRASH

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ABSTRACT

Drive shaft modeling effects frontal crash finite element simulation. A 35mph rigid barrier impact of a body on frame SUV with an one piece drive shaft and a unibody SUV with a two piece drive shaft have been studied and simulated using finite element analyses. In the model, the drive shaft can take significant load in frontal impact crash. Assumptions regarding the drive shaft model can change the predicted engine motion in the simulation. This change influences the rocker @ B-pillar deceleration. Two modeling methods have been investigated in this study considering both joint mechanisms and material failure in dynamic impact. Model parameters for joint behavior and failure should be determined from vehicle design information and component testing. A body on frame SUV FEA model has been used to validate the drive shaft modeling technique by comparing the simulation results with crash test data. These drive shaft models have also been applied to a unibody SUV model to demonstrate the contribution of drive shaft for simulated frontal impact performance.

INTRODUCTION

It has been well accepted that vehicle crash performance depends on not only the design of structure components but also vehicle system kinematics, such as mass distribution and engine motion [1], [2].

The drive shaft in truck/SUV power train assembly plays a very impotent role in frontal impact crashes because it carries load from the vehicle's front to the rear suspension. It has been found from vehicle crash safety development that the load in drive shaft can be significant especially for compact truck/SUV since crush space is limited. Therefore, rocker @ B-pillar pulses can be affected by the load level and timing. Drive shaft design has been listed in the category of new generation safety structure research.

Contributions of the drive shaft are studied by test review and finite element simulation using Radioss Crash. A body on frame SUV with a one-piece drive shaft and a unibody SUV with a two-piece drive shaft are selected to perform frontal impact analyses. The drive shafts are meshed as shell elements according to their design geometry. The universal joints and slip joints are modeled in two different ways, detailed mechanism and simple common nodes connection, to find out a proper modeling approach to obtain drive shaft contribution to vehicle crash performance. The modeling methods are applied to a body on frame SUV with a one-piece drive shaft.

It has been discovered from the FEA results that joint modeling can change predicted engine motion in the simulation. This change may also affect predicted rocker @ B-pillar responses, such as deceleration, velocity and displacement. The model with details of the slip joint and the universal joint leads to better correlation with recorded crash test data on engine velocity change, especially for the first 40 milliseconds. The model with simple common nodes connection shows a time delay on velocity change because the mechanism of the joints is neglected.

A modeling approach is suggested that considers both joint mechanisms and material failure in dynamic impact. Parameters should be determined by vehicle design information and component test. The modeling technique has also been applied to a unibody SUV. Drive shaft contribution to load path and rocker @ B-pillar deceleration are analyzed.

There are two key factors to develop a good finite element model, mesh quality and proper mechanisms. Drive shaft is an assembly related to a heavy mass. It has to be carefully modeled to achieve correct engine motion. The engine motion is important to predicted rocker @ B-pillar responses.

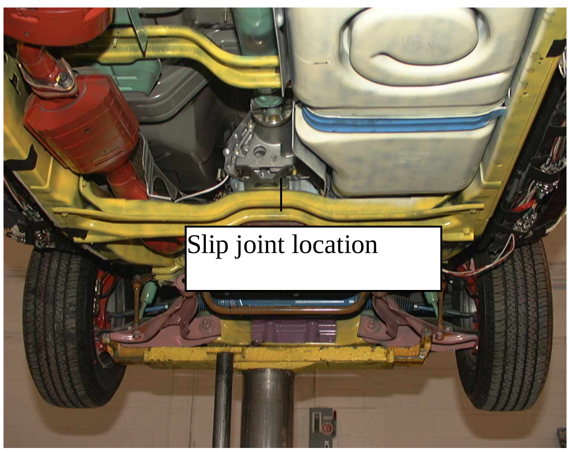
DRIVE SHAFT MECHANISM AND FEA MODEL

The drive shaft is an assembly in four/all wheel drive vehicles, which connects the transmission to the rear differential. It is not a structure component for crash energy management. However, its influence on vehicle crash behavior cannot be neglected because it is a load path to the rear suspension and connected to the engine mass. There are at least two joints in a drive shaft assembly. In addition, the drive shaft is connected to the mass of engine/transmission and rear suspension. The mechanism of drive shaft has significant influence on engine and rear suspension loading. This can affect engine motion as well as rocker @ B-pillar responses.

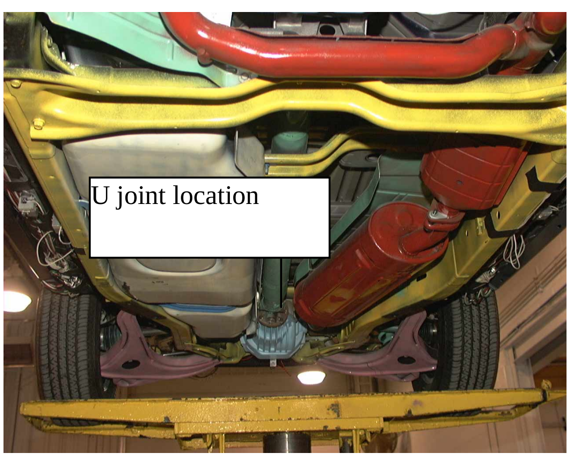
Drive Shaft Assembly

Figure 1-1 and figure 1-2 show two popular drive shafts used in today's truck/SUV packages.

Many light trucks and body on frame SUVs have adopted the one-piece drive shaft. It has a slip joint in front connected to transmission and a universal joint in rear connected to the rear differential.



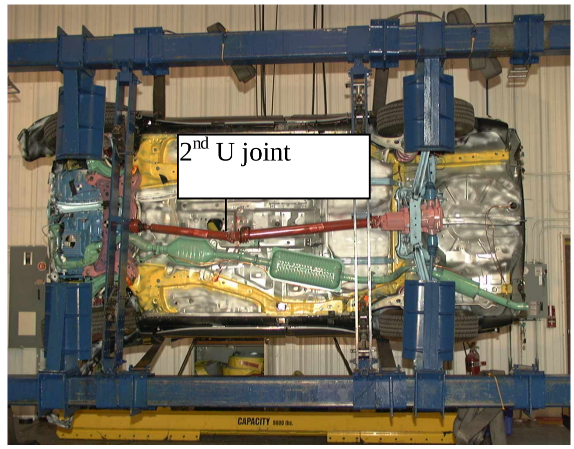
Front Connection to Transmission



Rear Connection to Differential

Figure 1-1: One-piece Drive Shaft

The two-piece drive shaft can be found in some unibody SUVs and four-wheel drive passenger cars. Similar to the one-piece drive shaft, it has a slip joint in the front and a universal joint in the rear connecting transmission to the rear differential. Different from a one-piece shaft, the two-piece drive shaft has another universal joint in the middle separating the shaft into two parts.



Additional U Joint

Figure 1-2: Two-piece Drive Shaft

Apparently, the two pieces drive shaft has more flexibility than the one-piece shaft because of the second joint. On the other hand it is longer than the one-piece drive shaft.

Drive Shaft FEA Model

There are two different approaches considered in this study to identify a better way to develop a drive shaft finite element model for frontal impact crash simulation. They are validated in a body on frame SUV equipped with one-piece drive shaft.

The first approach is to use simple common nodes connection regardless the joints flexibility. It is based on the consideration of load path. The model is shown in figure 1-3.

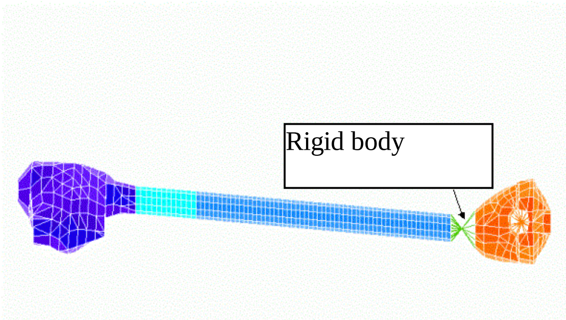


Figure 1-3: Common Nodes Connection Model

The second approach is to model all the joints in detail using special elements provided by Radioss shown in figure 1 – 4. The slip joint is modeled by a spring with six degrees of freedoms. A force–deflection curve defined by the gap of the physical joint, controls the axial translation of slip joint. The other five translations and rotations are defined by strong stiffness according to the mechanism of the joint. The universal joint is modeled by a group of truss elements. They share a common node in the center of the joint. This gives free rotations but no translations.

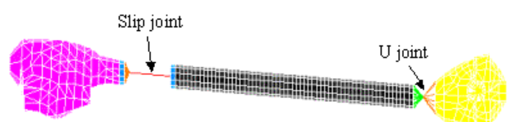


Figure 1-4: Detail Model with Mechanism

DRIVE SHAFT LOADING AND EFFECT ON ROCKER PULSE

Drive shaft is not an energy-absorbing component for crash safety design. However, it is an important load path that transfers impact force from the front of the vehicle to the rear suspension. It has been found from vehicle crash tests and finite element simulations that the drive shaft can bend or even break during a 35MPH rigid barrier impact. Examples are shown in figure 2-1 and figure 2-2. This indicates that the shaft can be loaded with significant force. This force influences the rocker @ B-pillar pulse.

Figure 2-3 is a force deflection curved obtained from a compression test of a two-piece drive shaft. It shows that the force through the drive shaft can be over 6000 lbs. Another comparison of 35MPH FEA results demonstrates the effect of drive shaft loading on rocker @ B-pillar deceleration. Figure 2-4 shows two FEA pulses. The two models are identical except that the drive shaft is not loaded in model 2 in the simulation. It is found that the two pulses are not similar. Loading the drive shaft causes a peak in deceleration around 40 milliseconds, which may affect the predicted vehicle crash performance.

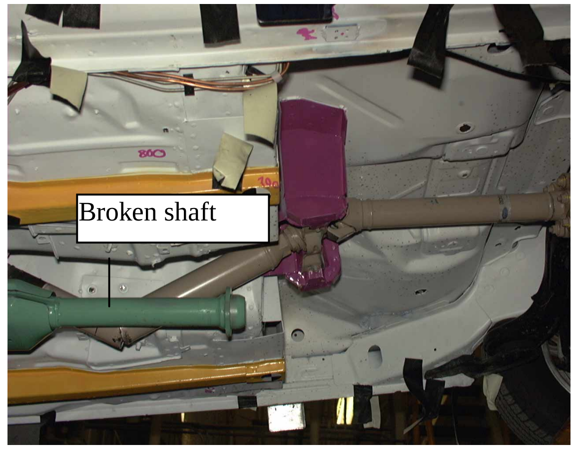


Figure 2-1: Broken Drive Shaft During Crash

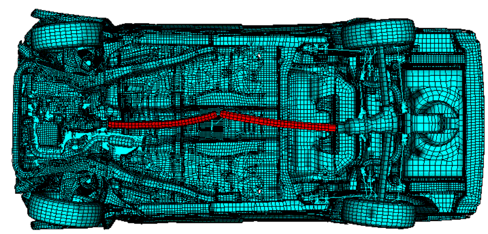


Figure 2-2: Bend Drive Shaft in Simulation

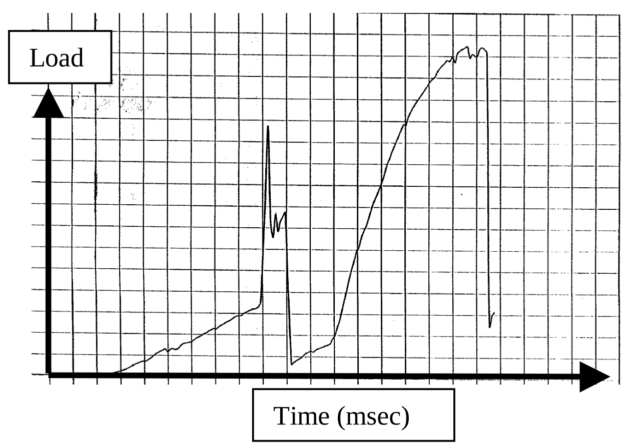


Figure 2-3: Force Deflection of Drive Shaft Compression

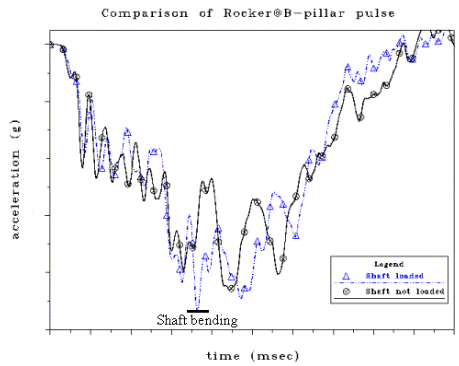


Figure 2-4: Comparison Of Rocker @ B-Pillar Pulses

MODELING EVALUATION BY 35MPH RIGID BARRIER IMPACT SIMULATIONS

The two approaches for drive shaft modeling, common nodes connection and detailed mechanism, are validated by full vehicle crash finite element analysis. A body on frame SUV is selected for the simulation. The model is developed by HyperMesh with about 180,000 shell elements shown in figures 3-1 and 3-2. The system is given an initial velocity of 35MPH towards a rigid wall. Two full vehicle models have been built. One is modeled with a common nodes connection drive shaft and the other is modeled with a detailed mechanism of the drive shaft. The rest of the two models are identical. The analysis is done by Radioss Crash on Cray C90.

Figure 3-1 Finite Element Model Perspective View

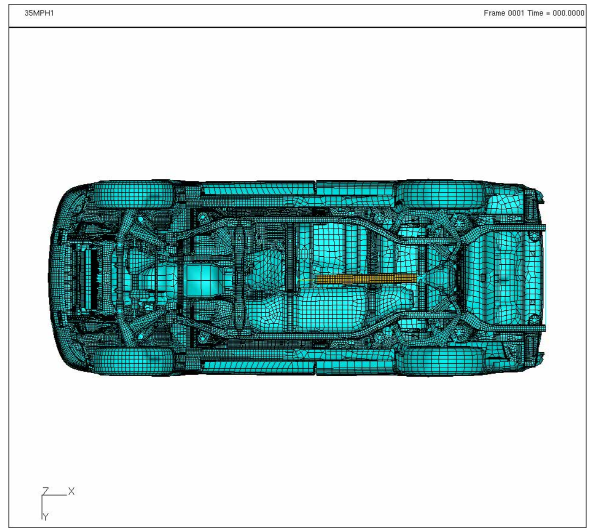


Figure 3-2 Finite Element Model Bottom View

Rocker @ B-pillar responses including deceleration, velocity and displacement are recorded through time history plots, which are the important information related to occupant injury during frontal impact. Engine motion is also checked because of its heavy weight that may affect rocker pulses.

The time history plots are used to investigate the effect of drive shaft modeling. The simulation results are analyzes by comparing engine motions and rocker @ B-pillar responses. Both FEA and barrier crash test data have been collected to do the comparison.

Figures 3-3 and 3-4 compare engine deceleration and velocity change during crash. Engine motion cannot be overlooked because of its heavy weight in vehicle system.

It can be seen in figures 3-3 and 3-4 that the model with common nodes connection decelerates faster than the test data. The model with detail mechanism drive shaft correlates better to test data especially for the first 40 milliseconds. This can be explained by engine behavior during crash and how the modeling approach affects engine motion. Reviewing engine deceleration and velocity of 35MPH barrier test results, there is always a flat portion for the first few milliseconds. It indicates that engine can travel freely in this period of time. This is the contribution of slip joint. It allows engine move with the initial velocity for two to three inches before reaching the designed gap. Drive shaft rotation can also be seen in high-speed crash films. It means that there are no toques applied to the component during crash. The detail mechanism model represents the function of the physical drive shaft while the common nodes connection approach locks all the degrees of freedom.

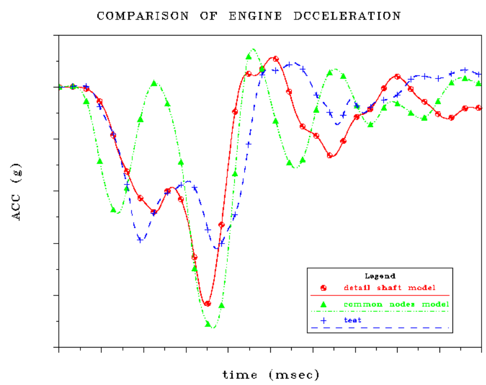


Figure 3-3: Comparison of Engine Deceleration

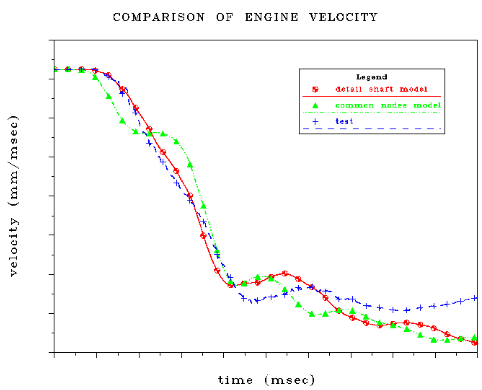


Figure 3-4: Comparison of Engine Velocity

Figures 3-5 and 3-6 are the comparisons of rocker @ B-pillar decelerations and velocities. Model with detail mechanism drive shaft also shows better correlation to test results.

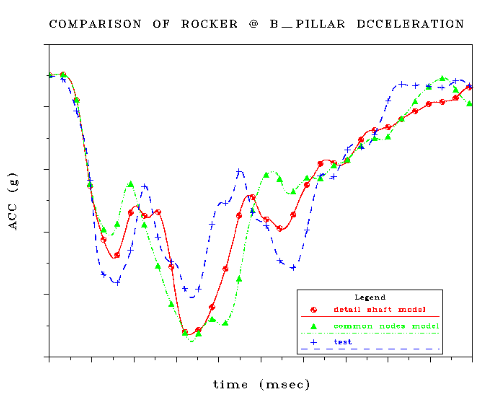


Figure 3-5: Comparison of Rocker @ B-Pillar Deceleration

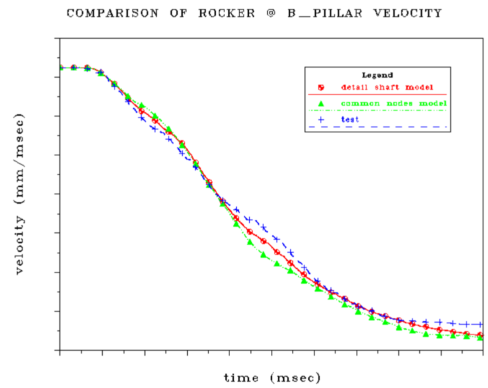


Figure 3-6: Comparison of Rocker @ B-Pillar Velocity

Comparing FEA and test results shows that drive shaft modeling is important for developing a good finite element model for crash simulation. The modeling approach will definitely influence predicted engine motion. It may also affect rocker @ B-pillar response.

DEVELOPMENT OF A TWO PIECE DRIVE SHAFT MODEL

It is important for frontal impact crash analysis to develop a finite element model with a detailed drive shaft mechanism. Engine motion as well as full vehicle response to the crash cannot be correctly simulated otherwise. A two-piece drive shaft is selected here to develop a proper method for frontal impact FEA modeling. This drive shaft is included in a unibody SUV.

The physical drive shaft is shown in figure 2-2. It has a slip joint in front connected to transmission. The gap of the slip joint is two inches. There are two universal joints in this drive shaft assembly. One is in the rear connected to rear differential and the other is in the middle right before the connection to floor pan. The middle connection is basically a bracket that is design to break at given load to avoid significant drive shaft loading.

The detail model of the slip joint is shown in figure 4-1. A beam type spring in Radioss Crash is used to represent the joint. The spring has six degrees of freedom, three translations and three rotations, which are defined by stiffness and force deflection function. Rotational stiffness as well as shear stiffness of the spring is given large values that allow no movement in those directions based on the mechanism of slip joint.

The axial translation of the spring is controlled by a function of force and deflection, which is defined according to the gap and material property of the shaft.

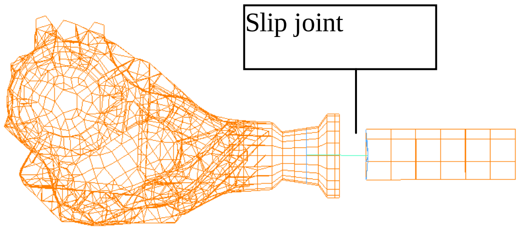


Figure 4-1: Slip Joint Detail Model

Universal joints are also modeled here by beam type springs. The three translation stiffness are given large values to block the sliding movements. Zero stiffness is given to all rotations to allow free rotation according to the joint mechanism.

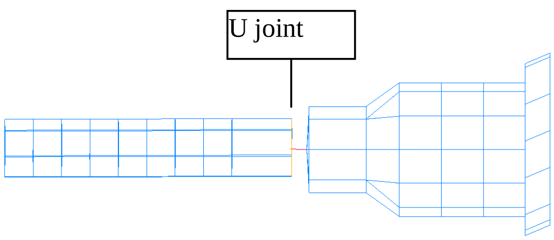


Figure 4-2: Universal Joint Detail Model

The breakable connection to floor pan is modeled by beam type spring with a failure criterion. The test result of component compression is used to define spring function and the criterion to break the connection
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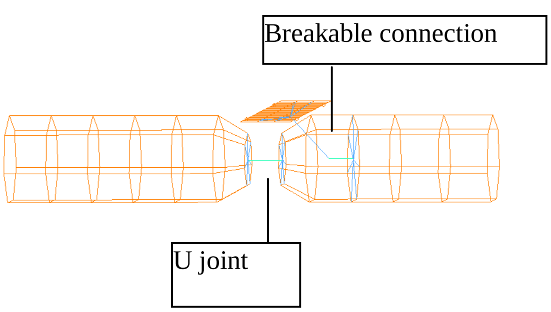


Figure 4-3: Breakable Connection Model

A full vehicle 35MPH rigid barrier impact simulation is done by Radioss. A unibody SUV with a two-piece drive shaft is selected for the analysis. The drive shaft modeling follows the method just mentioned. Drive shaft behavior is observed from the animation during the crash simulation.

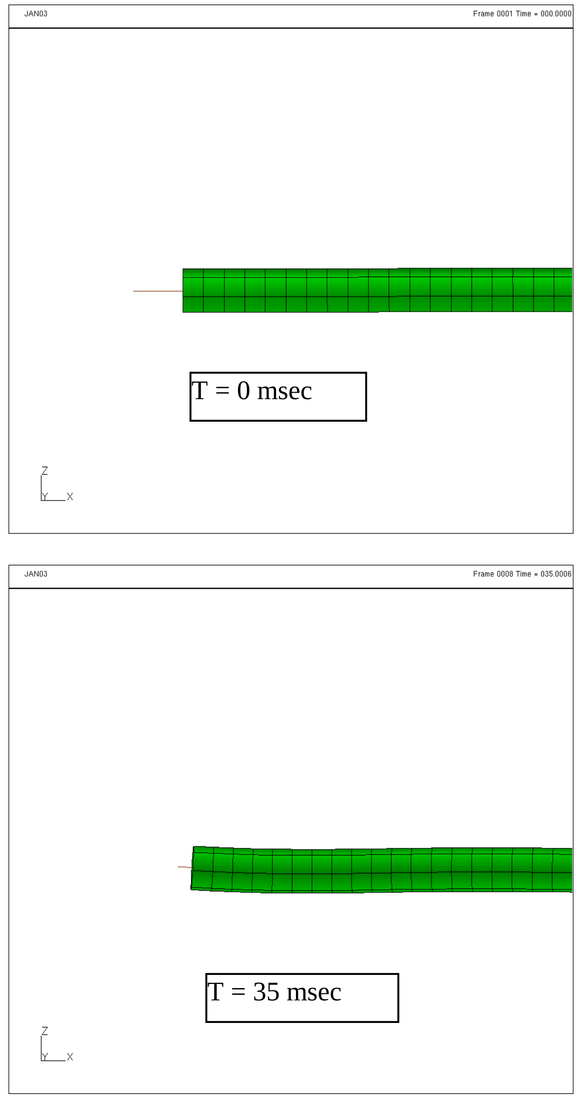
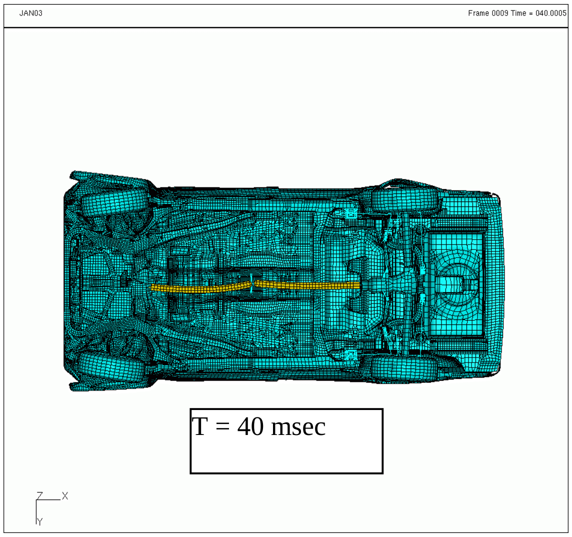


Figure 4-4: Slip Joint Behavior

Figure 4-4 demonstrates the deformation of slip joint. It can be seen from the animation that the spring is compressed from 0 to 35 milliseconds reflecting the design of the gap.



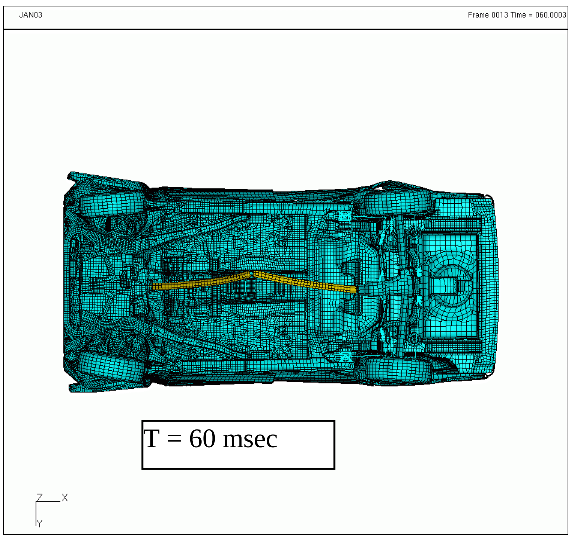


Figure 4-5: Breakable Connection Behavior

Figure 4-5 shows drive shaft motion and deformation related to the breakable connection to floor pan. Drive shaft deforms at 40 milliseconds after slip joint has fully compressed, deformation can be seen on drive shaft. It indicates that the shaft has been loaded. The drive shaft floor connection is broken at 60 milliseconds. The shaft moves away from the centerline of the vehicle and an angle can be seen. It is caused by the rotation of the universal joint. The animation is in good correspondence with test film. It demonstrates the method of drive shaft modeling represents the mechanism of the assembly design.

DISCUSSION AND CUNCLUSION

The drive shaft is an assembly in four/all wheel drive vehicles serving as a connection between front transmission and rear differential. It is not a structure component for crash energy management. However, its influence on vehicle crash behavior in frontal impact cannot be neglected because it is a load path to rear suspension and connected to engine mass.

The drive shaft can take significant load during frontal impact depending on vehicle weight and crash mechanisms. Test examples show that the drive shaft can break or bend during a 35MPH rigid barrier impact. This indicates that the shaft can be loaded with significant force. This force may have an influence on the rocker @ B-pillar pulse.

The drive shaft is also an assembly with complicated mechanisms. There are at least a slip joint and a universal joint in the system. The behavior of the joints influences the engine motion and the full vehicle response during crash.

Modeling of the drive shaft is one of the key factors to develop a good finite element model for crash simulation. Two modeling approaches, common nodes connection and detailed mechanism, are validated by full vehicle crash finite element analysis and crash test comparison. It is found that a model with a detailed mechanism drive shaft model correlates well with test data especially for the first 40 milliseconds. A model with common nodes connection shaft model predicts decelerations faster than the test. This can be explained by engine behavior during crash and how the modeling approach affects engine motion. Detailed mechanism model represents the function of drive shaft assembly while the common nodes connection approach locks all the freedoms of the slip joint and universal joint.

A modeling method is correlated in this study using a two-piece drive shaft. The slip joint is modeled as a beam type spring with no rotation or shear motions. The axial movement is controlled by a force deflection function obtained from the joint design and the shaft material property. The universal joint is modeled by beam type spring with no translations and free rotations according to the mechanism of the joint. The breakable attachment to floor pan is also modeled by a spring element with a failure criterion based on drive shaft component compression test data. The model has been applied to a unibody SUV. FEA analysis of drive shaft behavior in a 35MPH rigid barrier impact simulation shows good correlation with test results.

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